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Abstract:

In the past four decades, commercial vehicles have increased in weight and number. Because these increases may effect highway structures, four Ontario surveys of commercial vehicles were done, which included records of weights, and inter-axle spacings or their equivalent base lengths. The 1975 and 1979 surveys were done by selecting, weighing and measuring loaded trucks at weigh stations throughout the Province. A weigh-in-motion method was used for the 1980/81 survey on Highway 69 north of Parry Sound and the 1982 survey on Keele Street in Downsview. For comparison, two samples from weigh-in-motion surveys in the United States are included.

There is no significant evidence to suggest that the heaviest trucks in Ontario (top one percent) increased in weight from 1975 to 1982. The weigh-in-motion samples taken in the U.S. were similar to those taken in Ontario except that a much larger fraction of the Ontario samples had weights exceeding 500 kN. From the 1982 survey, there is an indication that trucks with equivalent base lengths between 8 and 18 m are occasionally considerably overloaded in urban areas.

Key Words: weigh-in-motion surveys, live load, vehicle weights, weight control, truck configuration, equivalent base lengths

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Surveys of Commercial Vehicles Weights 1975 to 1982

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Ontario Ministry of Transportation and Communications
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1/ Introduction

Most bridges in the Ontario highway system were designed in accordance with the AASHTO* Specifications [1] in which an idealized truck weighing 320 kN (32 650 kg) is assumed. The original highway live loads were developed prior to 1944. During the past four decades, the volume and weight of commercial vehicular traffic has increased. Because of these increases, and changes in design methods, factors were specified in subsequent editions of the AASHTO Specifications which had the effect of uniformly increasing the magnitude of the original highway live loads. In 1967 the Ontario Ministry of Transportation and Communications (MTC) began a series of commercial vehicle surveys. During the 1967, 1971, 1975 and 1979 surveys, samples of commercial vehicles were selected, measured and weighed at various weigh stations throughout the Province. As an extreme example, the heaviest truck in the 1975 survey weighed 650 kN (66 300 kg). A review of the methods used in selecting vehicles and the results of the previous surveys are included in the MTC Publication RR 230 [2]. During the same period, the MTC bridge testing program verified that the majority of existing bridges had adequate strength to support much heavier vehicle loads than those originally idealized in the AASHTO Specifications.

Based on the surveys and bridges tests, decisions were made to increase the legal weight limits for Ontario highways and to prepare a new bridge design specification. In 1971 major changes in the legal weight limits were incorporated in the Ontario Highway Traffic Act. The current Act [3], which has weight limits similar to the 1971 Act, was passed in 1978. As an example of a heavy vehicle which does not require a special permit under the current Act, an eight-axle truck can travel with a gross weight of 622 kN (63 500 kg) if it satisfies certain length and front axle weight criteria. In 1979 the first *Ontario Highway Bridge Design Code* (OHBDC) was issued [4]. As part of the highway live load provisions, an idealized truck weighing 700 kN (71 400 kg) was specified. Thus, the legal weight limits and the design live loads have been increased substantially in recent years.

When the OHBD Code was issued, it was resolved that rational relationships would be maintained between observed vehicle weights, legal vehicle weight limits and the weight of the idealized truck specified for bridge design. It was recognized also that the random phenomenon of multiple truck presence is very important in determining the magnitudes of some structural effects (shears, moments, axial forces, deflections, etc.). Multiple presence is particularly important for those effects with large "tributary areas"; that is, large areas of bridge deck on which loading contributes to the magnitude of the structural effect. Thus, Phases I, II and III of *A Study of Commercial Vehicles and Their Multiple Presence* [5, 6, 7] were carried out under the Ontario Joint Transportation and Communications Research Program (Projects No. 23116 and No. 23141). It was known that the methods used in the previous surveys tended to bias the weight data because only those trucks were weighed and measured which went through a weigh station and appeared to be heavily loaded. Therefore, the first two objectives of Phases I, II and III of the study were:

a/ To develop a method of doing a traffic survey which includes recording truck weights and "equivalent base lengths" (a term explained subsequently) while traffic is moving on a highway.

b/ To compile data from surveys at several locations.

A method, similar to that used by Moses [8], was developed for determining vehicle weight based on the response of an instrumented highway bridge. In contrast with the method used by Moses, the method used for Phases I, II and III is suitable for bridges with longer spans. For the former method, spans less than 26 m are selected; in this study, bridges with spans of 36.5 and 40.3 m were used.

The objectives of this publication are to summarize the weight data obtained during Phases I, II and III of *A Study of Commercial Vehicles and Their Multiple Presence* [5, 6, 7] and to compare the results with those obtained during the 1975 and 1979 surveys. These results will also be compared with those of similar surveys in United States.

* American Association of State Highway and Transportation Officials

2/Statistical Analysis for Limit States Designs

By using specified live loads and related code provisions, a bridge designer is making implicit predictions of the largest live load effects which will occur in structural bridge members. Such prediction is important because a limit state is avoided during a reference period only if the largest live load effect during the period added to the dead load effect is less than the corresponding resistance or serviceability limit. A reference period is associated with each largest live load effect — a bridge lifetime for ultimate limit states, a shorter period for serviceability limit states.

The magnitude of a live load effect fluctuates. Many peak values occur in one reference period; frequently they are caused by independent loading events. For some loading processes, the statistical distribution of the largest value in a reference period can be predicted [9, p. 271] based on a sample of live load response data. The mean value of this distribution, that is, the "mean largest effect", is a best statistical prediction of the largest live load effect in a future reference period. As a first step in the calibration of a statistically based code, idealized live loads are selected such that the effects which they cause have a reasonably consistent and known relationship with the corresponding mean largest effects.

For effects which have small tributary areas, there is a direct correlation between structural effects and loads — the largest magnitude of the static component of a live load effect is caused by the heaviest axle, axle group or vehicle which occupies the tributary area. In this case, the idealized loads for use in design can be selected based on statistics of load rather than statistics of structural effects. For effects which have larger tributary areas, structural effects and truck weights are not well correlated because multiple vehicle presence is an important random phenomenon. As an example, a loading event which includes a few critically located trucks with intermediate weights may cause a larger structural effect than the loading event which includes the heaviest truck.

Common statistical methods for calculating the distribution for the largest value during a reference period do not take account of physical and legal limits. These limits are important in predicting the largest loads caused by traffic. Thus, predicting mean largest axle and truck loads is more difficult than predicting mean largest values for many other stochastic variables. Nevertheless, if observed truck weights and legal vehicle weight limits increase, the mean largest load for a reference period must be expected to increase also. Therefore, surveying truck weights and comparing them to legal weight limits and design live loads is an essential step in maintaining rational relationships between observed bridge loads, legal limits and design live loads.

3/The Ontario Bridge Formula (OBF) and Selection of a Highway Live Load for Design

In addition to truck weights, the weights of individual axles were recorded during previous surveys. To facilitate the analysis of the weight data, an "equivalent base length" was calculated for each group of adjacent axles and each truck as a whole. This length parameter, which depends on the distribution of axle weights and interaxle spacing, is based on defining an alternative load. The alternative load is uniformly distributed on the equivalent base length B_M, has a total weight equal to that of the corresponding axle group or truck, and causes maximum moments which do not deviate unreasonably from those caused by the axle group or truck applied directly. The equation for length B_M was developed based on the calculation of maximum moments in simple span members [10].

$$B_M = \frac{4 \sum_{1}^{N} |P_i x_i|}{\sum_{1}^{N} P_i} \cdot \frac{2(N-1)}{bN} \left[\frac{\sum_{1}^{N} P_i x_i}{\sum_{1}^{N} P_i} \right]^2$$

where: P_i = the ith axle load of the sequence
x_i = distance between P_i and the axle closest to the centre of gravity of the sequence
b = distance between the outside axles (base length)
N = number of axles in the sequence

Applying the alternative load of length B_M was found to be adequately accurate for calculating shear forces, negative moments and positive moments in members continuous over two or more spans [10].

Frequency tables for weight of axle groups (including whole trucks) and equivalent base length have been plotted for the 1967, 1971, 1975 and 1979 surveys [2]. In the 1980, 1981 and 1982 surveys, truck weights were obtained by a weigh-in-motion method but axle weights were unavailable; their responses could not be separated because the instrumented bridge spans were long relative to the axle spacings [6]. Therefore, Figures 6(a) through 6(d) were plotted as frequency tables of truck weight and equivalent base length. Each column in a table gives the frequencies of weight categories for trucks with equivalent base lengths in a narrow range. Because of the linear relationship between loads and maximum effects, these frequencies correspond to frequencies of the maximum structural effects which would occur if the trucks in the specific equivalent base length range crossed a bridge one at a time.

The Ontario Bridge Formula (OBF) was developed as a means for determining rational and consistent legal weight limits for all configurations of commercial vehicles and their axle groups. The OBF was used first for the Ontario Highway Traffic Act of 1971. Using the Formula, a weight limit is calculated as a function of equivalent base length. Compliance with the weight limit provides an implicit limit on the magnitude of those live load effects which have small tributary areas and, therefore, are not influenced by multiple vehicle presence. The weight limit W_M is calculated as follows:

In kN, $W_M = 9.806 (10.0 + 3.0B_M - 0.0325 B_M^2)$

In kg, $W_M = 10000 + 3000 B_M - 32.50 B_M^2$

where length B_M is in metres.

From the results of previous surveys, it was observed that the recorded weights of vehicles and axle groups very infrequently exceeded the weight limit W_M by more than 98 kN (10 000 kg). By adding this weight margin to the above equation, a second equation, the Maximum Observed Load (MOL) was formulated. This curve is used as a weight limit for special permit vehicles. Also, the axle weights and dimensions of the idealized truck in the OHBD Code were determined so that the weight and equivalent base length data for the truck plot very closely to the MOL curve [2, p. 9].

During calibration of the OHBD Code, a relationship was established between structural effects caused by the idealized highway live loads and the corresponding predicted mean largest effects. The magnitudes of the latter effects exceed the former by 10 to 17% [11]. This relationship was taken into account in the Code calibration.

4/Sampling Methods

The four surveys done in Ontario between 1975 and 1982 provide four samples of trucks which have used the provincial highway system. However, the sampling methods differed and these differences must be considered when results are compared. Two samples from weigh-in-motion surveys in United States are also included.

4.1/ The 1975 Survey

During a separate study prior to the 1975 survey, the numbers of trucks to be selected were determined for each truck configuration and each weigh station (Figure 1) [2]. The weigh stations were not used for law enforcement during the survey. Only trucks which appeared to be heavily loaded were weighted and measured. In sparse traffic, approximately one out of three trucks was selected; in dense traffic approximately one out of ten was selected. For the figures, 6492 trucks from the survey are used (none had special permits). Survey data were added subsequently during 1975 from a few additional weigh stations.

4.2/ The 1979 Survey

Between February 1, and July 31, 1979, survey data were obtained from charge reports collected from the Truck Inspection Stations across the Province. Except for approximately 100 trucks for which the records were illegible, all trucks apprehended for violations of the legal weight limits or the Registered Gross Weight throughout Ontario were included. For the figures, 4782 regular permit vehicles and 119 special permit vehicles are included. The frequency of each truck configuration is shown in Figure 1.

4.3/ The 1980/81 Survey [5, 6]

Surveys were done at the Shawanaga River Bridge on Highway 69 between Parry Sound and Sudbury on July 12, and August 6, 1980, and on September 30, and October 1, 13, 14 and 15, 1981. Traffic was free moving, travelling between 50 and 90 km h. The strains of the main bridge girders were recorded and pictures were taken of each truck which crossed the bridge. Using a weigh-in-motion method to process the data, gross weights and equivalent base lengths were calculated for both north- and southbound trucks. Calculations for all trucks which crossed the bridge were impossible because occasionally the equipment malfunctioned and the recorder was stopped while tapes were changed. These interruptions created a selection process; however, the selection of trucks was not biased with respect to configuration or weight. For each configuration, the number of trucks observed and the number for which weights and equivalent base lengths were calculated are listed in Figure 1.

4.4/ The 1982 Survey [7]

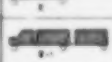
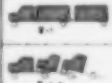
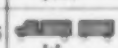
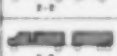
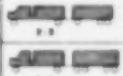
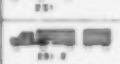
The survey was done at the Keele Street Overpass over Highway 401 in Downsview on December 13, 14, 15, and 16, 1982. Traffic was frequently slow, congested and occasionally stopped because of a signal light beyond the bridge. The strains of main bridge girders were recorded and video tapes were taken during daylight hours. Because of several problems with the records, only 13 hours of data were processed. During that period, more than 20 000 southbound vehicles crossed the bridge. Using a signal on one channel of the tape recording, tall vehicles were flagged when they interrupted a light beam 1.7 m above the pavement. The flagged vehicles were identified using the video playback. Among the 1005 trucks which were seen, more than 600 had only two-axles and caused insignificant increases in girder strain; weight calculations were not done for these trucks. Again, equipment malfunctions over certain periods disallowed weight-in-motion calculations for some trucks. Also, when two trucks were on the same span, their weights were not separated. For each configuration, the number of trucks observed and the number for which weights and equivalent base lengths were calculated are listed in Figure 1.

4.5/ Surveys Done in United States [12, 13]

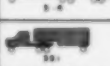
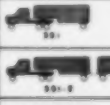
During 1982, weigh-in-motion surveys were done in several states [13]. Bridges were instrumented and the weight calculations were done by the method developed by Moses [8]. Traffic was not interrupted during the surveys and the equipment was intentionally inconspicuous. Two samples are included for comparison in this report:

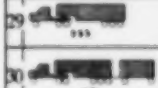
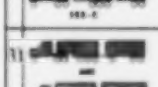
- The Ohio sample is the sum of observations in the east- and westbound lanes of Interstate Highway 80 in central Ohio. Classification of trucks is not done in exactly the same way as in Ontario but, as nearly as possible, the frequencies of each configuration are listed in Figure 1. The total number in the sample is 1489 trucks. Ohio was selected because it is a nearby state with available weigh-in-motion data.
- The 36-site sample is the sum of observations taken at 36 sites in a state where very heavy trucks are occasionally observed. The number of trucks in this sample is 7354.

Figure 1/ Frequencies of Commercial Vehicle Configurations

FHWA CODE	VEHICLE CONFIGURATIONS	1975 SURVEY	1979 SURVEY	1980 & 1981 SURVEYS ON HWY 69	1982 SURVEY ON KEELE ST	OHIO 1982 SURVEY
1		13	518	337 / 186	689 / 25	96
2		1	16	4 / 3	0	0
3		0	13	5	0	0
4		0	0	0	0	0
5		1	23	5 / 4	0	5
6		2	11	3 / 3	0	0
7		0	0	0	0	0
8		44	15	15 / 15	13 / 13	22
9		14	7	3 / 3	0	4
10		346	387	84 / 61	25 / 38	150
11		0	0	2 / 2	0	0
12		1	0	0	0	0

NOTE: FOR THE 1980-81 AND 1982 SURVEYS, THE UPPER LEFT NUMBERS WERE OBSERVED, THE LOWER RIGHT NUMBERS WERE WEIGHED

FHWA CODE	VEHICLE CONFIGURATIONS	1975 SURVEY	1979 SURVEY	1980 & 1981 SURVEY ON HWY 69	1982 SURVEY ON KEELE ST	OHIO 1982 SURVEY
13		2	19	2 / 2	4 / 4	3
14		0		0	0	0
15		913	362	197 / 90	89 / 81	61
16		4	0	3 / 3	0	0
17		0	3	1 / 0	0	0
18		0	0	0	0	0
19		123	6	2 / 2	0	0
20		41	0	5 / 3	0	0
21		24	0	3 / 2	0	0
22		7	2	5 / 5	4 / 4	22
23		6	2	0 / 0	0	0
24		3750	1662	540 / 480	82 / 60	1260
25		83	195	17 / 14	0	0

FHWA CODE	VEHICLE CONFIGURATIONS	1975 SURVEY	1979 SURVEY	1980 & 1981 SURVEYS ON HWY 69	1982 SURVEY ON KEELE ST	OHIO 1982 SURVEY
26		190	139	56 / 51	1 / 1	0
27		14	9	2 / 2	0	0
28		1	0	0	0	0
29		856	1183	322 / 287	11 / 11	26
30		12	27	30 / 27	1 / 1	0
31		8	9	1 / 1	0	0
32		0	4	0	0	0
33		103	135	124 / 110	0	0
34		29	25	1 / 1	1 / 1	5
35		2	3	0	0	0
36		2	5	0	0	0
37		0	2	0	0	0
		NOT INCLUDED	NOT INCLUDED	NOT COUNTED	122 / 9	NOT COUNTED

5/ Truck Weights for All Configurations

Histograms of weight for trucks of all configurations are shown in Figures 2(a) through 2(d) for the four surveys done in Ontario. The sampling methods appear to have determined the shapes of the histograms for the 1975 and 1979 surveys. In 1975 it was determined that configuration No. 24 would compose 58% of the sample and no other configuration would compose more than 13%. Because of their dominant numbers, loaded trucks of configuration No. 24 dominate Figure 2(a) causing relatively large frequencies around the weight of 330 kN. The weights of other configurations are included in the wide weight range between 40 and 660 kN. Therefore, the histogram in Figure 2(a) has a wide base and an approximate "bell" shape. In contrast with the 1975 survey, in 1979 configuration No. 24 composed only 34% of the sample. Because all trucks surveyed in 1979 violated weight regulations, truck weights within each configuration are closely grouped and four common configurations cause four peaks in the histogram as identified in Figure 2(b).

In 1980/81 the truck samples were taken at specific times on one rural highway. Weights were calculated for 86% of those trucks which crossed the bridge during the survey periods; the selection of trucks was not biased with respect to truck configuration or weight. In 1982 an urban location was used and many two-axle trucks were not weighed because they caused insignificant increases in girder strain. Weights were calculated for 57% of those trucks which had three or more axles. Within this group, the selection was not biased with respect to truck configuration or weight. From Figures 2(c) and 2(d), it appears that truck samples selected with minimum configuration and weight bias have weight histograms characterized by positive skew and relatively large frequencies between 100 and 200 kN. The mean weights of both samples are between 200 and 250 kN. In contrast with Ontario, positive skew is not as noticeable because very few trucks in the samples from United States had weights greater than 500 kN.

In Figure 3 cumulative frequencies are plotted for the weight of all trucks in each sample. Throughout most of the weight range, the curves for the 1975 and 1979 surveys are to the right of the curves for the 1980/81 and 1982 surveys because the earlier surveys included only loaded trucks. The curve for the 1979 survey is furthest to the right because only trucks which violated weight regulations were included. For weights greater than 200 kN, the curve for the 1982 survey is further to the left — that is, this sample contains fewer heavy trucks because it was taken in urban traffic where there were relatively few trucks with more than five axles. From Figures 2 and 3 it can be seen that the heaviest truck in each of the Ontario samples was between 610 and 680 kN. The largest truck in the Ohio sample had a weight of approximately 511 kN. The largest two trucks in the 36-site sample had weights exceeding 667 kN (although their exact weights were not recorded).

Figure 2(a)/ Histogram of Vehicle Weight for all Commercial Vehicles

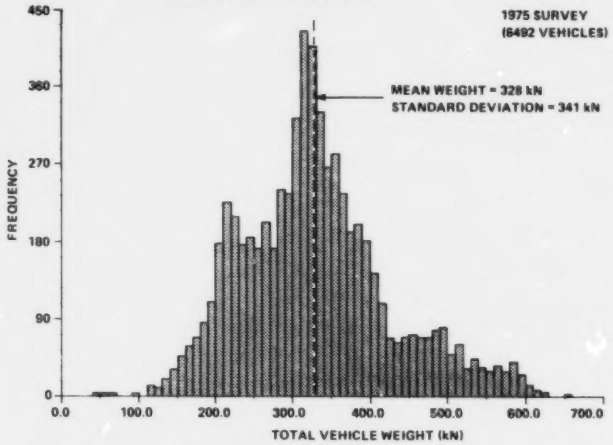


Figure 2(b)/ Histogram of Vehicle Weight for all Commercial Vehicles

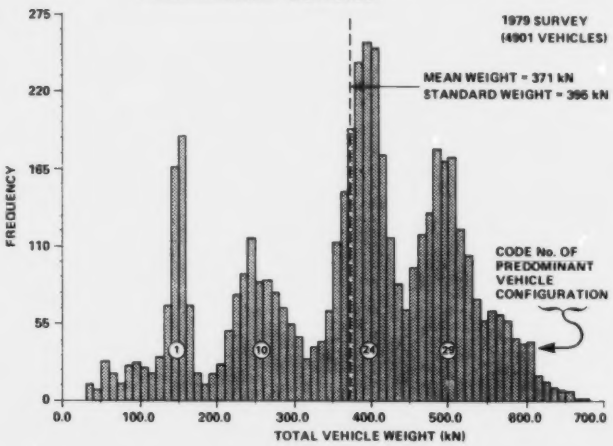


Figure 2(c)/ Histogram of Vehicle Weight for all Commercial Vehicles

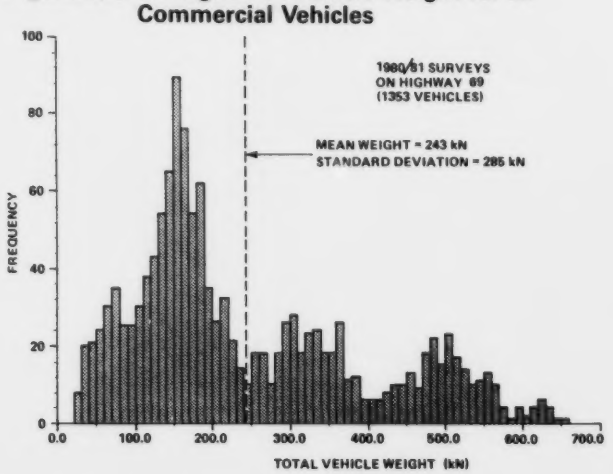


Figure 2(d)/ Histogram of Vehicle Weight for all Commercial Vehicles

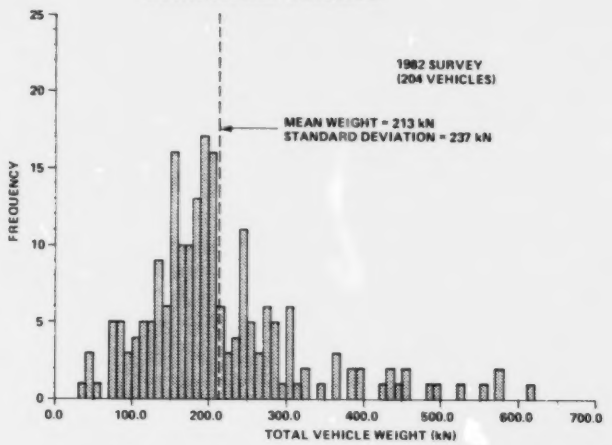


Figure 2(e)/ Histogram of Vehicle Weight for all Commercial Vehicles

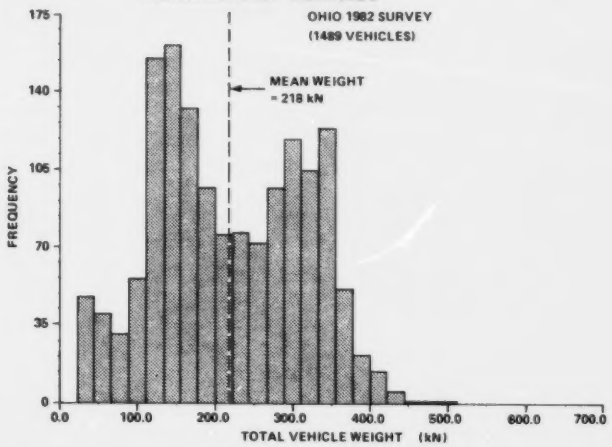


Figure 2(f)/ Histogram of Vehicle Weight for all Commercial Vehicles

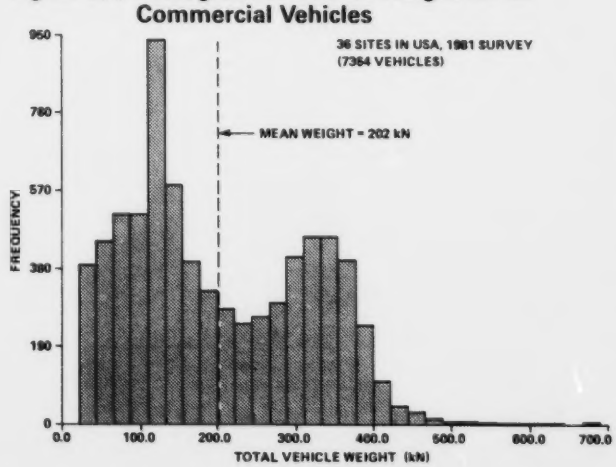


Figure 3/ Cumulative Frequency Distributions of Vehicle Weight for all Commercial Vehicles

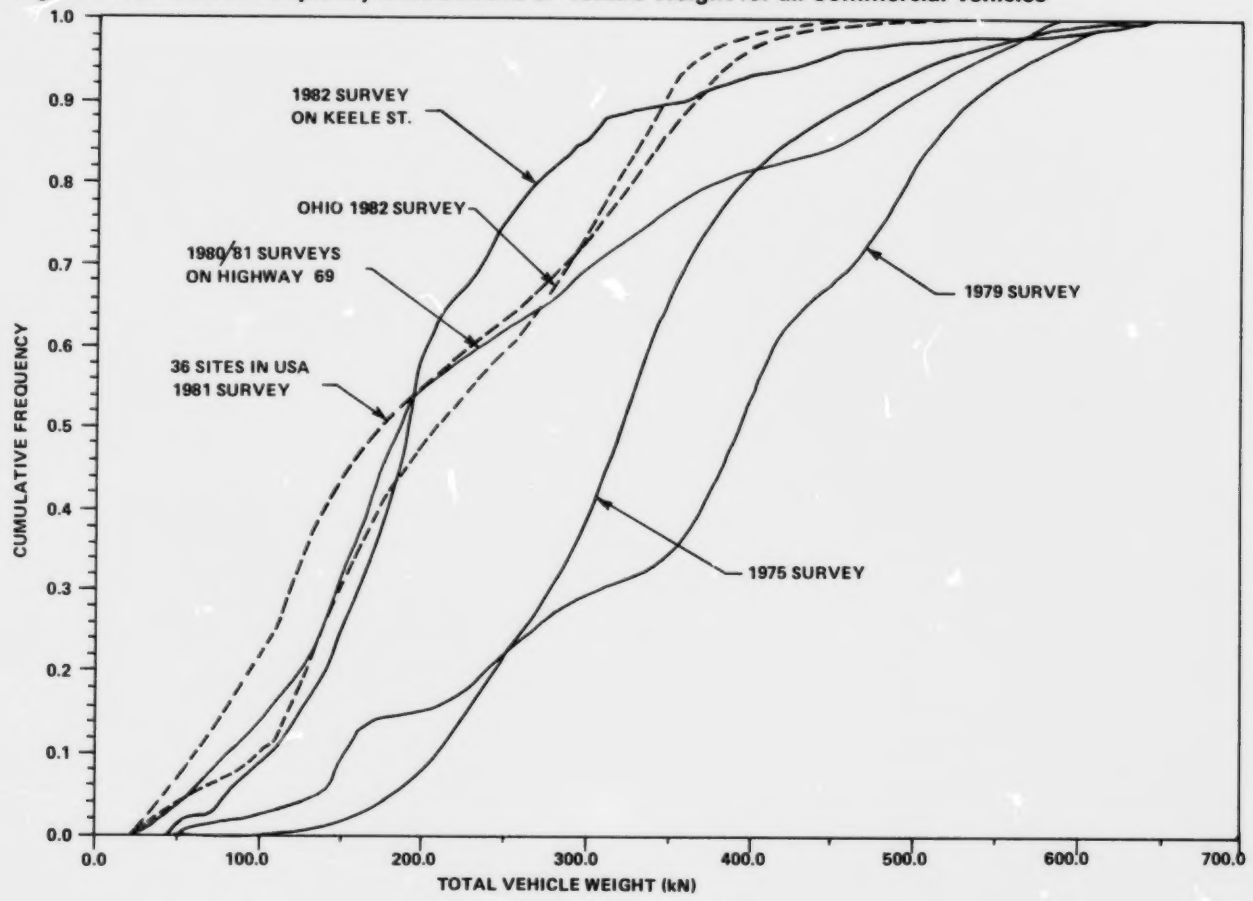


Figure 4(a)/ Histogram of Vehicle Weight for Vehicles of Code No. 24 Configuration

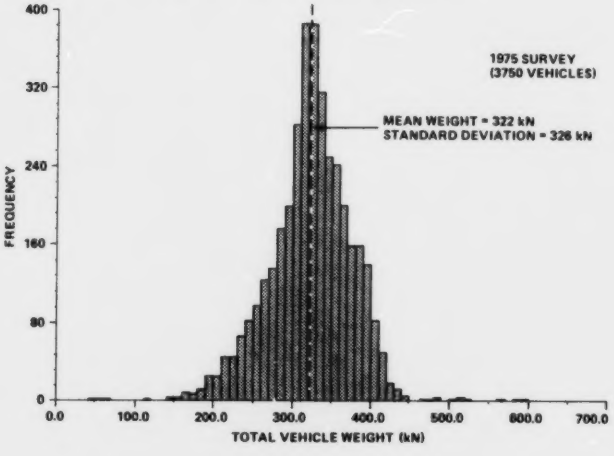
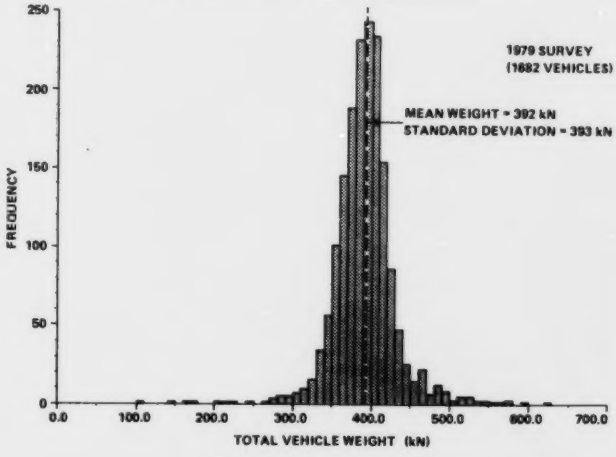


Figure 4(b)/ Histogram of Vehicle Weight for Vehicles of Code No. 24 Configuration



6/Truck Weights for Configuration No. 24

Figure 4(c)/ Histogram of Vehicle Weight for Vehicles of Code No. 24 Configuration

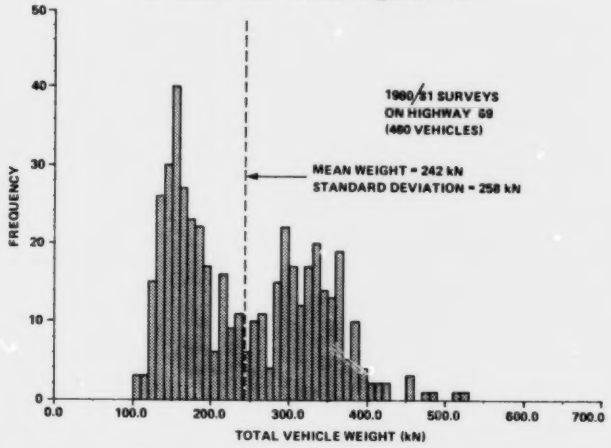


Figure 4(d)/ Histogram of Vehicle Weight for Vehicles of Code No. 24 Configuration

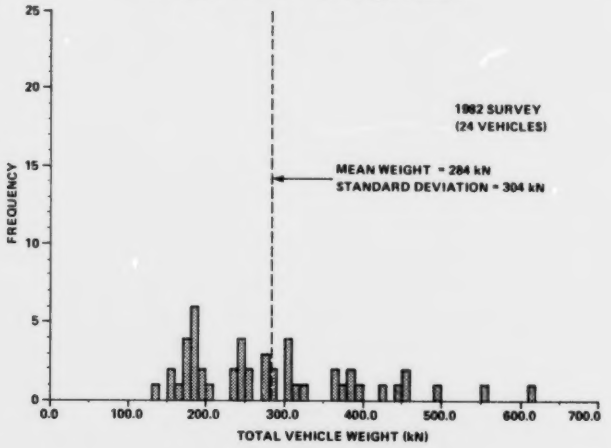
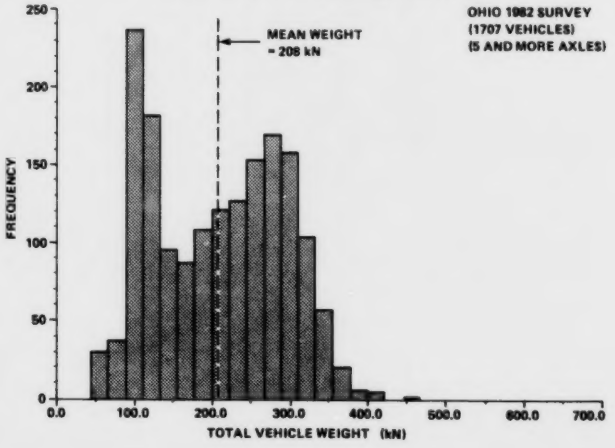


Figure 4(e)/ Histogram of Vehicle Weight for Vehicles of Code No. 24 Configuration



Histograms of weight for trucks of configuration No. 24 are shown in Figures 4(a) through 4(d) for the four surveys done in Ontario. Cumulative frequencies are charted in Figure 5. Because only loaded trucks were included in the 1975 and 1979 surveys, the histograms in Figures 4(a) and 4(b) are narrow, with relatively large frequencies in a few weight intervals near the mean truck weight. Because unloaded and loaded trucks were included in the 1980/81 survey, the histogram in Figure 4(c) has two regions of truck weights with relatively large frequencies. The region with weights less than the mean value corresponds to unloaded trucks; the region with weights larger than the mean value corresponds to loaded trucks.

The weights of trucks with five or more axles observed in Ohio [2] are shown in the histogram in Figure 4(e). The characteristics of the histogram are the same as those described above for the Ontario weigh-in-motion samples, however, the heaviest truck observed in the Ohio sample was approximately 460 kN which is considerably lighter than the heaviest in the Ontario surveys.

As indicated in Figure 5, the trucks in the 1979 survey were predominantly heavy; they all violated weight regulations. From Figure 5, it is apparent that many trucks in the 1980/81 and 1982 surveys were lighter than those in the earlier surveys because unloaded trucks were included in the 1980/81 and 1982 surveys but were not included in the earlier surveys. The 49 trucks of configuration No. 24 in the 1982 survey were relatively heavy compared to the 460 trucks of the same configuration in the 1980/81 survey. This difference may be attributed to the urban location of the 1982 survey. Trucks of configuration No. 24 are more manoeuvrable than those with more axles. Shippers in urban areas, therefore, often prefer to use No. 24 trucks heavily loaded rather than switch to alternative configurations of greater capacity but reduced manoeuvrability.

Figure 5/ Cumulative Frequency Distributions of Vehicle Weights for Vehicles of Code No. 24 Configuration

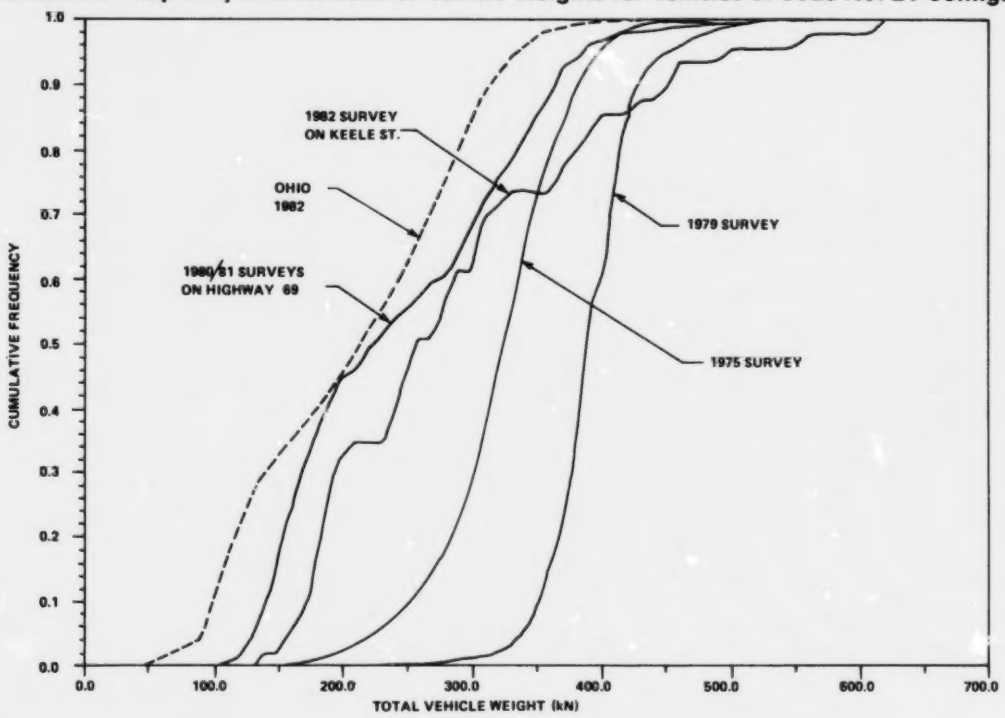


Figure 6(a)/ 1975 Survey - Frequencies of Commercial Vehicles for Categories of Vehicle Weight and Equivalent Base Length

TOTAL NUMBER OF COMMERCIAL VEHICLES -- 6492

Weight in kN	Equivalent Base Length In Metres															
	0	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32
0- 20																	
20- 40																	
40- 60	4																
60- 80	2																
80-100		1	1	1													
100-120		1	4	7													
120-140			10	7	3	1	2	3	4								
140-160		4	28	20	8	3	3	1	9	2							
160-180		1	48	37	4	1	4	7	10	16							
180-200			83	38	4	7	4	11	23	18	7	1					
200-220		3	209	54	4	6	11	17	46	41	13	1					
220-240			152	47	5	3	7	18	58	71	23	1					
240-260			34	67	3	3	5	24	81	100	32	7			1		
260-280			4	132	6	10	14	46	111	103	50	8					
280-300			2	14	8	16	18	38	123	195	56	3	1				
300-320				1	8	15	26	63	242	311	73	9	1				
320-340					4	20	30	56	233	300	87	4	1	2			
340-360					4	28	27	49	136	228	68	4	2	1			
360-380					5	35	31	42	102	122	61	4	1	2			
380-400					3	94	61	33	71	86	30	2	1				
400-420					1	61	36	29	38	58	25	3					
420-440						11	13	12	31	42	17	2	1				
440-460							6	10	32	64	24	2	1				
460-480						2	3	6	39	72	14	1					
480-500							1	8	24	62	30		1				
500-520						1		2	42	47	15	1					
520-540								1	30	38	5						
540-560									18	36	5	1					
560-580								2	14	29	12	1					
580-600							1		5	30	20	2	1				
600-620									3	7	8	1					
620-640										2	1	2					
640-660								1									
660-680																	
680-700																	
700-720																	
720-740																	

ONTARIO BRIDGE FORMULA (OBF)

LEGAL LIMIT 63 500 kg (622.7 kN)

MOL

Figure 6(b)/ 1979 Survey - Frequencies of Commercial Vehicles for Categories of Vehicle Weight and Equivalent Base Length

TOTAL NUMBER OF COMMERCIAL VEHICLES -- 4901

Weight in kN	Equivalent Base Length In Metres															
	0	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32
0- 20																	
20- 40		1	8	3													
40- 60		4	20	3	1	1	1	5									
60- 80		7	12	4		1	1	2	3								1
80-100		8	21	9	7	2	3	1	1								
100-120		9	17	8	3	2	1	1		1							
120-140		22	49	18	2	2	1	1	3								
140-160		41	223	70	11	3	4	1	1								
160-180		5	28	36	8		5	1	2								
180-200		1	7	6	5	4		1	2		2	2					
200-220		1	10	12	12	5	6	6	3								
220-240		1	75	32	4	4	8	19	11	11							
240-260			32	75	9	1	5	17	33	25	3						
260-280			17	38	8	2	5	13	31	41	6	1					
280-300			1	22	5	1	8	16	27	33	6	1					
300-320			1	12	3	4	5	9	21	12	7						
320-340				1	5	10	5	19	20	15	3	2					
340-360				4		7	8	24	65	33	30	3	2		1		
360-380					1	11	17	23	97	136	50	2	4	1			
380-400					2	41	65	31	98	173	73	9	1	1			
400-420						60	93	29	54	124	70	10	2	1	1		
420-440						11	25	23	40	54	41	5					
440-460						2	9	14	31	54	33	4	1	1			
460-480						1	16	27	54	102	46	3	2		1		
480-500							15	34	105	145	38	8	2	1	1		
500-520							3	18	94	114	50	7	1				2
520-540							2	10	52	81	25	3		1	1		
540-560								3	25	60	28	4	1				
560-580								2	26	46	19	3	1	1			
580-600									8	44	28	1	1				
600-620									5	22	25	1	1				
620-640										7	11	4					
640-660									2	6	5						
660-680										1	1						
680-700																	
700-720																	
720-740																	

ONTARIO BRIDGE FORMULA (OBF)

MOL

LEGAL LIMIT 63 500 kg (622.7 kN)

7/ Truck Weights and Equivalent Base Lengths

Figure 6(c)/ 1980/81 Surveys on Highway 69 - Frequencies of Commercial Vehicles for Categories of Vehicle Weight and Equivalent Base Length

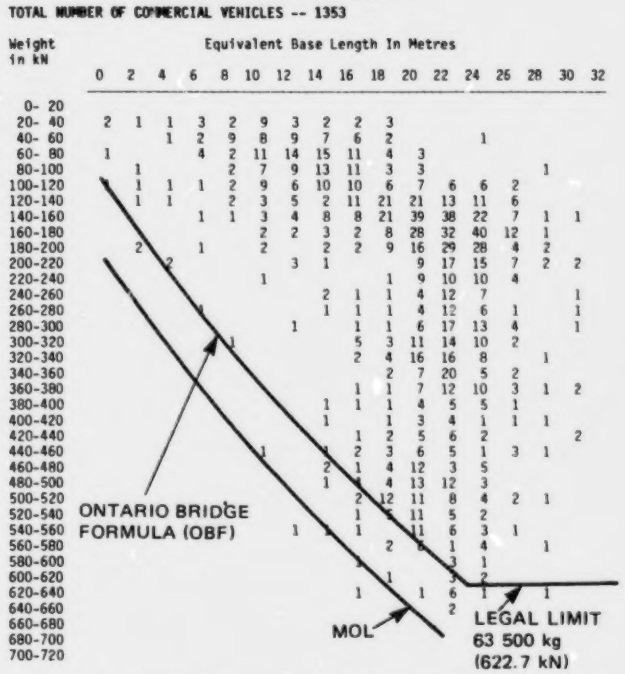
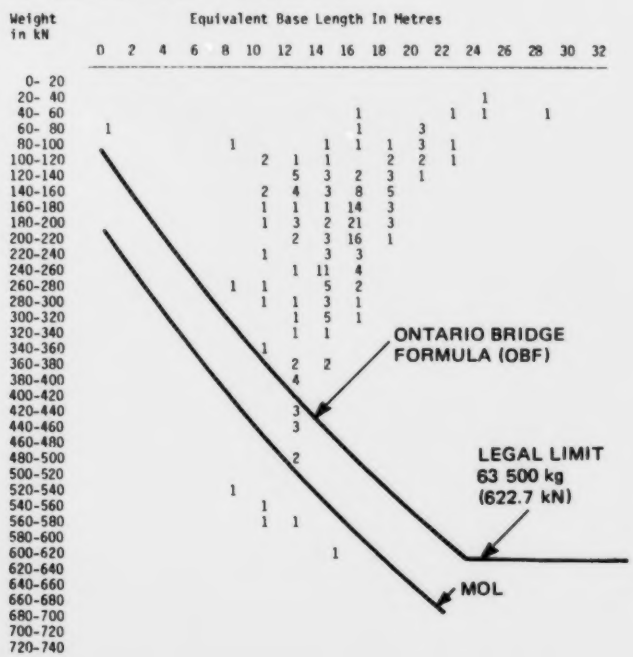


Figure 6(d)/ 1982 Survey on Keele St. - Frequencies of Commercial Vehicles for Categories of Vehicle Weight and Equivalent Base Length



Frequency tables for gross truck weight and equivalent base length are shown in Figures 6(a) through 6(d) for the four surveys done in Ontario. On each the OBF and MOL curves are plotted. By comparing Figures 6(a) and 6(b) to Figure 6(c), it is seen that the following observations, which were made previously for the 1975 and 1979 surveys [2], also apply to the 1980/81 survey:

- A large majority of trucks in the survey travelled with gross weights less than the value indicated by the OBF for their equivalent base lengths.
- With very few exceptions, trucks in the survey travelled with gross weights less than the value indicated by the MOL curve for their equivalent base lengths.

The long equivalent base lengths for light trucks shown on the right side of Figure 6(d) for 1982 survey are questionable data. For light vehicles, the weigh-in-motion calculation method has a tendency to indicate long equivalent base lengths because of other nearby light vehicles and because of electrical noise in the strain records. The five trucks in the 1982 survey with weights greater than 525 kN are of concern because they had relatively short equivalent base lengths and exceeded the weight indicated by the MOL curve. Two of the five trucks were of configuration No. 24. As earlier suggested, trucks with short equivalent base lengths are heavily loaded in urban areas because they manoeuvre more easily than the longer trucks designed for such loads.

Cumulative frequencies of weight for those trucks with equivalent base lengths between 18 and 22 m are charted in Figure 7 for the 1975, 1979, and 1980/81 surveys. The 1979 survey included the heaviest trucks. Unloaded as well as loaded trucks were included in the 1980/81 survey.

Figure 7/ Cumulative Frequency Distributions of Vehicle Weight for Vehicles with Equivalent Base Lengths Between 18 and 22 m

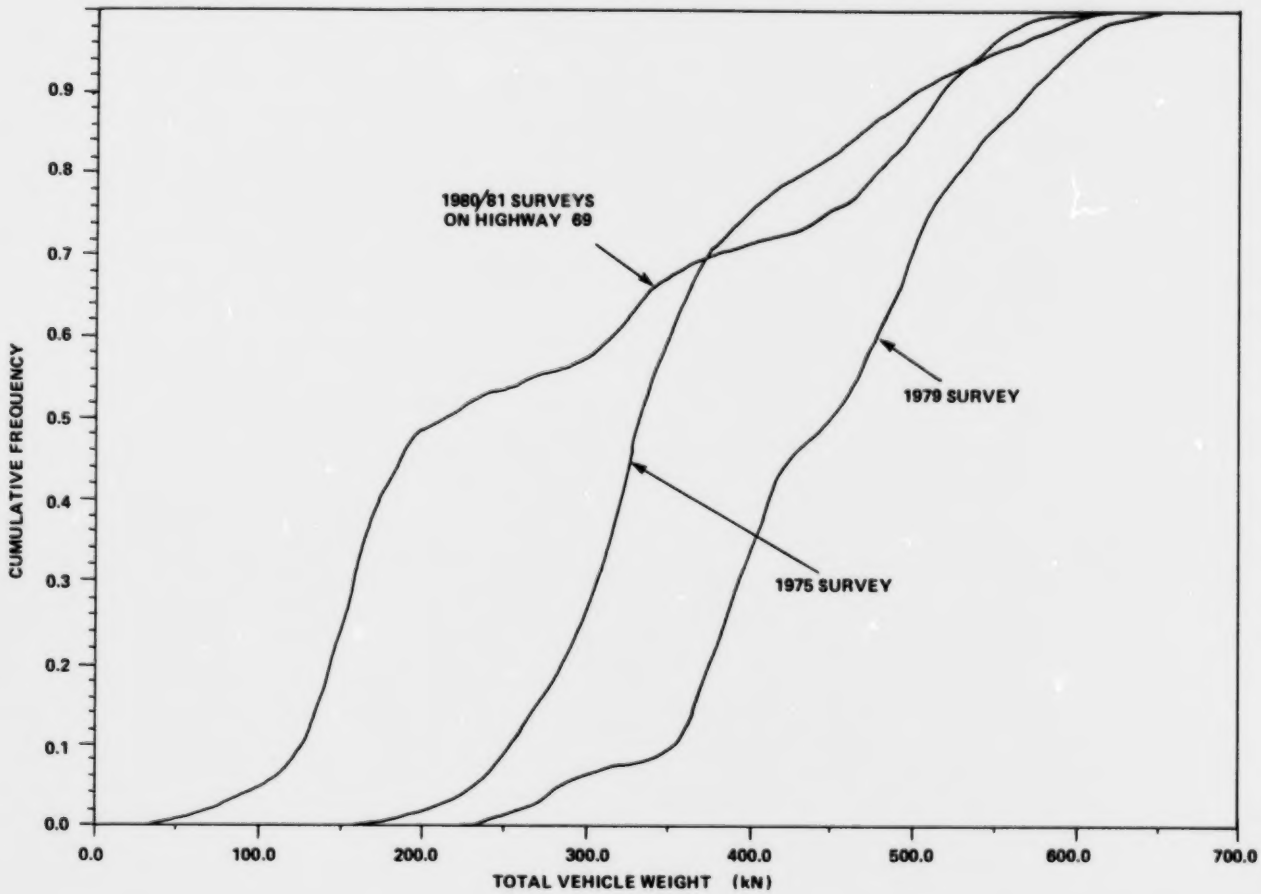
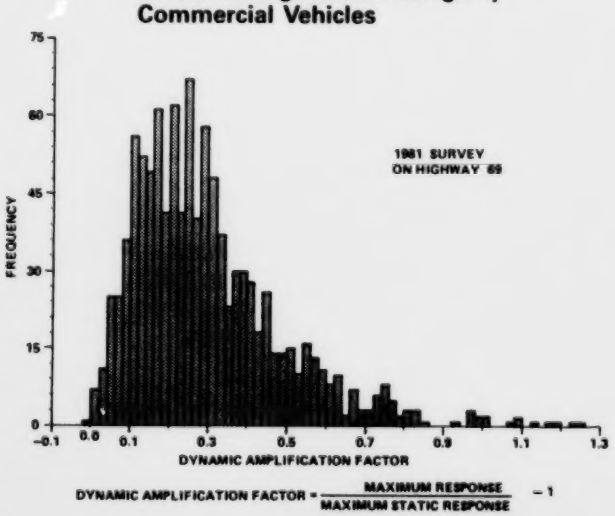
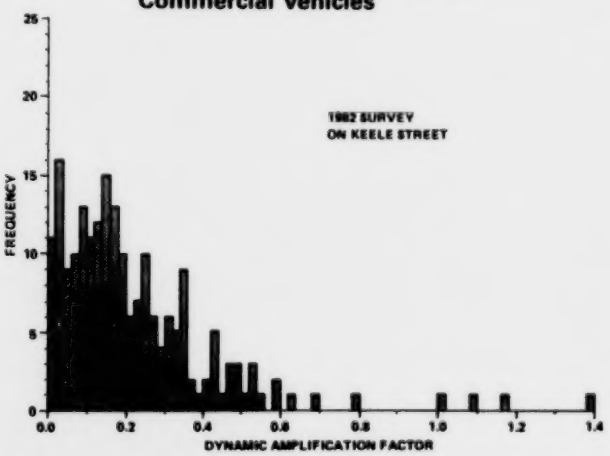


Figure 8(a)/ Histogram of Dynamic Amplification Factor During 1042 Crossings by Commercial Vehicles



$$\text{DYNAMIC AMPLIFICATION FACTOR} = \frac{\text{MAXIMUM RESPONSE}}{\text{MAXIMUM STATIC RESPONSE}} - 1$$

Figure 8(b)/ Histogram of Dynamic Amplification Factor During 204 Crossings by Commercial Vehicles



8/Data on Dynamic Bridge Response

For the weigh-in-motion calculations, the strain responses are added from adjacent girders under the vehicle and an idealized static response is fitted to the sum [6, 7]. Thus, a maximum static response is available from the calculations. The ratio of the maximum measured response during an event to the maximum idealized static response is calculated — this ratio minus one is defined as the "dynamic amplification factor".

The dynamic responses of adjacent girders are usually in phase and have similar amplitudes (a common characteristic of the fundamental mode of vibration). However, the girders immediately under the vehicle have much larger static responses than those which are more remote. Therefore, using the summed strain responses to calculate a dynamic amplification factor over-estimates the correct factor for girders immediately under the vehicle.

Histograms of the dynamic amplification factors obtained during the weigh-in-motion calculations are shown in Figures 8(a) and 8(b) for 1042 trucks from the 1981 survey and 204 trucks from the 1982 survey. In Figures 9(a) and 9(b) the frequencies of truck events are listed for various categories of truck weight and dynamic amplification factor. Although the factors are large, because of the calculation method described above, it is apparent from Figures 9(a) and 9(b) that there is an approximate inverse relationship between the dynamic amplification factor and truck weight — heavy trucks have relatively small, and light trucks relatively large factors.

Figure 9(a)/ 1981 Survey on Highway 69 - Frequencies of Commercial Vehicles for Categories of Vehicle Weight and Dynamic Amplification Factor

TOTAL NUMBER OF COMMERCIAL VEHICLES --1042

Weight in kN	Dynamic Amplification Factor													
	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3
0- 20														
20- 40			3	6	6	2	1	1						
40- 60		1	4	13	3	5	3		3					
60- 80		5	16	10	7	6	4	1	1	2				
80-100		2	14	4	12	3	4	2						
100-120		4	5	12	10	4	6	2	5			2		
120-140		5	20	21	9	6	3	3	1			1		2
140-160		12	30	34	15	10	4	4	2	2			1	
160-180		6	24	33	18	12	6	1	1	1	2		1	
180-200		3	9	21	15	8	8	2	1	1	1	1		
200-220		1	9	6	11	9	6	2	1		1		1	
220-240		7	6	3	3	5		1	1		1	1		
240-260		2	8	4	4	1	1	1	2					
260-280		3	9	4	3	2	1							
280-300		4	10	12	6	4	2	1						
300-320		4	10	9	3	4	2							
320-340		2	10	6	9	5	4	4						
340-360		2	3	4	8	3		1	3	1				
360-380		4	4	10	5	2	3	1	2		1			
380-400		3	2		2		3							
400-420		1	2	2	1	1	1	1						
420-440		4	5	2	1	2								
440-460		6	5	5	1				1					
460-480		2	7	5	3			2						
480-500	1	4	8	9	3	4	3							
500-520		6	14	8	3									
520-540		2	6	7	1									
540-560		2	7	8	1	1								
560-580		2	1	3	4									
580-600		2		2	1									
600-620		2	2	1		1								
620-640		1	4	4										
640-660			2											
660-680														
680-700														
700-720														
720-740														

Figure 9(b)/ 1982 Survey on Keele St. - Frequencies of Commercial Vehicles for Categories of Vehicle Weight and Dynamic Amplification Factor

TOTAL NUMBER OF COMMERCIAL VEHICLES -- 204

Weight in kN	Dynamic Amplification Factor														
	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4
0- 20															
20- 40											1				
40- 60		1	1								1	1			
60- 80			2		1	1								1	
80-100	1	2	3	1		1									
100-120	2	3	1	3											
120-140	2	3	4	4		1									
140-160	3	8	4	4	1	1	1								
160-180	2	6	3	4	2	1	1	1							
180-200	4	10	8	2	4	2									
200-220	6	4	4	5	3										
220-240	2	3	1		1										
240-260	3	11	1		1										
260-280	4	5													
280-300	4	2													
300-320	6	1													
320-340			1		1										
340-360	1														
360-380	4														
380-400	4														
400-420															
420-440	3														
440-460	2	1													
460-480															
480-500	2														
500-520															
520-540	1														

9/ Conclusions and Recommendations

1/ Because of the variations in sampling methods used in Ontario between 1975 and 1982, it is not possible to test the hypothesis that the Ontario truck population has not changed statistically during the period. Future surveys should adhere to one sampling method; that is, survey sites should be used repeatedly and sampling bias should be minimized.

2/ There is no significant evidence to suggest that the heaviest trucks in Ontario (top one percent) have increased in weight during the period 1975 to 1982. The top one percent of the 1979 to 1981 samples had weights greater than 610 kN. The top one percent of 1975 and 1982 samples had weights greater than 570 kN. The heaviest truck in each of the four surveys had a weight between 610 and 680 kN.

3/ The two weigh-in-motion samples taken in United States are similar to the weigh-in-motion samples taken in Ontario except that a much larger fraction of those taken in Ontario had weights exceeding 500 kN. However, the two heaviest trucks from the 36-site sample in United States fall in the same weight range as the heaviest from the four Ontario surveys.

4/ The frequencies of the various truck configurations change from one location to another. Thus, selecting the survey sites is an important consideration for a future survey. Because the number of locations suitable for a truck weight survey is restricted, classification and multiple presence surveys should be done at many sites, preferably in advance of the weight surveys.

5/ The 1982 survey indicates that trucks with equivalent base lengths between 8 and 18 m occasionally travel in urban areas with weights considerably greater than the value indicated by the MOL curve.

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